

A Pulsed Septum Magnet for the Fermilab Antiproton Source

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Abstract

A 2 meter curved pulsed septum magnet for use in the Fermilab Antiproton Source is described. The magnet produces a peak field of 6 kGauss at a current of 20,000 Amperes within a 0.4 msec long pulse. The field uniformity obtained is $\Delta B/B < 0.2\%$ out to 3.8 cm from the copper septum. Power enters the magnet from the center resulting in very simple ends and the magnet incorporates a 0.5 cm steel guard which reduces the field to < 1.4 Gauss in the zero-field region. The total septum thickness is 1.3 cm. The vacuum enclosure doubles as the stacking fixture for the magnet laminations allowing easy assembly of a magnet with a 50 m radius of curvature.

I. Introduction

Five septum magnets are used in the Tevatron I Antiproton Source - one for injection into the Debuncher of antiprotons from the production target, one for extraction into the Debuncher to Accumulator beamline, two for injection into the Accumulator from Debuncher, and one for injection of protons into the Debuncher directly from the 8 GeV booster. The required fields in all the magnets lie in the range 5-6.5 K Gauss for an 2.0 meter long magnet. All locations have very tight geometrical constraints which lead to requiring a total septum thickness of less than or equal to 1.3 cm, and which also require producing a curved septum to avoid losing approximately 1 cm of aperture to sagitta.

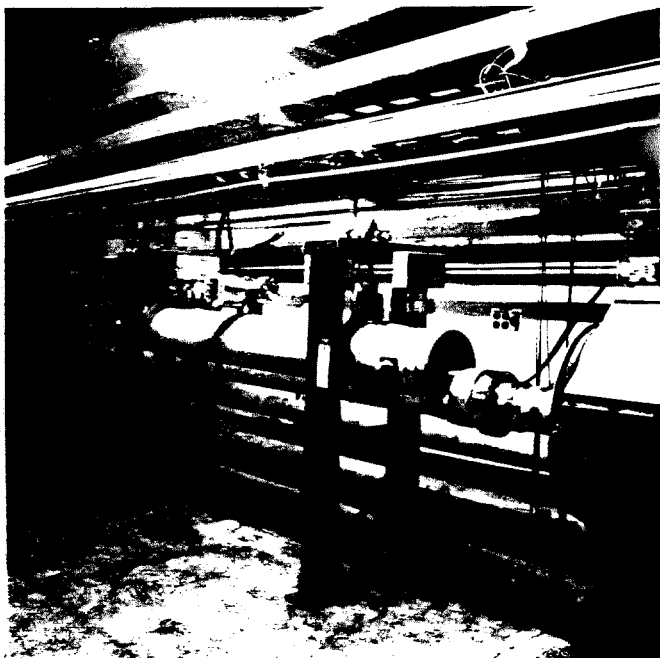


FIG. 1 Septum Magnet at the Injection into the Debuncher

The magnetic field quality requirements are fixed by requiring that the septa produce an emittance dilution of less than 2% for the smallest emittance beam anticipated. This translates into a field uniformity specification of 0.2% over the region from 0.3 cm to 3.7 cm from the copper conductor. It is also desirable that the field on the field free side of the septum be less than a few Gauss.¹

II. Magnet Design and ConstructionDesign

Figure 2 shows the cross section of the septum magnet. The total septum thickness of 1.3 cm is made up of four components: (1) a copper bus carrying a pulsed current of 20,000 amp, (2) a stainless steel plate bonded to the copper for reinforcement for the magnetic forces, (3) a sheet of kapton insulation and (4) a low carbon steel plate to shield the circulating beam magnetically.

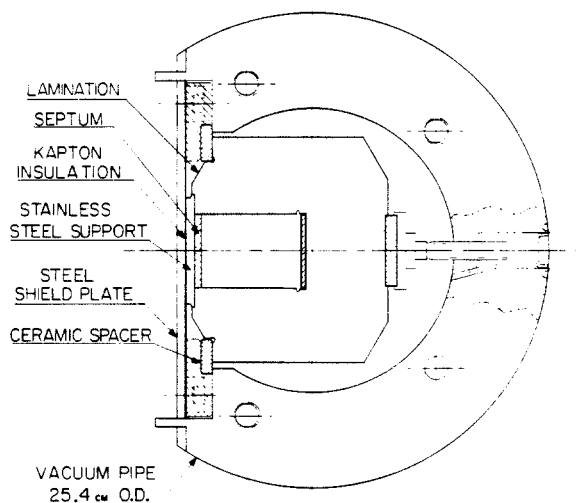


FIG. 2 Septum Magnet Cross Section

Alignment and Vacuum Pipe

The vacuum enclosures doubles as a stacking fixture for the magnet. The laminations are stacked and clamped in a 50 m radius of curvature. The curvature is required to increase the effective horizontal aperture. The "C" shaped cross section of the stacking fixture is machined from a 25.4 cm O.D. with a 15.2 cm I.D. hot finished seamless carbon steel tube (grade C1026). The tube is first rough machined and then annealed to remove any residual stresses. The only critical machining is the curved surface where the ceramic alignment rails are clamped. The tube is machined on a computer numerical controlled horizontal milling machine.

*Operated by the Universities Research Association, Inc. under contract with the U.S. Department of Energy.

Lamination

The magnet laminations were punched from 0.35 mm electrical steel type M-22. A phosphate surface insulation resistance, AISI C-4, was used. This treatment withstands stress-relief annealing. Because of the high vacuum requirements, 10^{-8} TORR, the laminations were vacuum baked at 780°C for two hours. This degassing process is required to bakeout the residual gasses trapped in the metal during fabrication. The laminations are supported at three points. The alignment is made on two curved rails made of alumina ceramic. Maximum accumulating tolerances of ± 0.1 mm were achieved. The ceramic rails were made straight and clamped on the curved surface machined on the alignment and vacuum pipe. This resulted with a satisfactory constant tensile stress of 16% of the allowable stress for the alumina ceramic.

The Coil

The coil is manufactured in three pieces; the septum and two inner conductors. The power enters the magnet from the center resulting in very simple ends. (See Figure 3.) The inner conductors are wrapped with a 0.4 mm thickness of kapton and held in position with stainless steel fasteners which are held inside the lamination grooves under spring forces. The septum conductor is bonded to the stainless steel back up support plate by the explosion-cladding process. This was required after oven brazing of the copper to the stainless steel was deemed unacceptable due to voids in the bonding surface. A copper clad plate was ordered, and septum strips were machined clamped on the flat surface of a planer.

The magnet is designed to be pulsed at a 1200 Hz rate with a .02% duty cycle. With a pulsed current of 20,000 amp, taking in account the skin effect on the copper, this results in an average power of only 34.3 watts. Cooling is provided by radiation only. A temperature gradient of 15°C was calculated between the copper in the septum and the air in the tunnel enclosure.

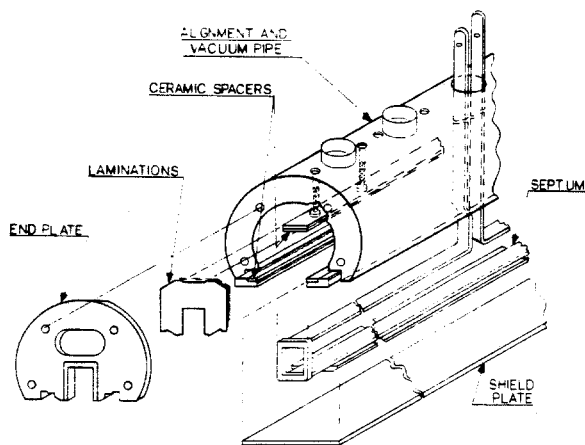


FIG. 3 Septum Magnet Assembly

Assembly

The vacuum pipe is also the stacking fixture for the magnet. The laminations are stacked on two ceramic rails. The rails are clamped on the curved surface of the alignment pipe by steel bars which are bolted on the pipe. The two rails are set parallel to each other and the steel bars are tack welded to the pipe. Figure 3 shows the magnet assembly. The laminations are stacked from each end starting with a center lamination core with a rectangular hole on the inner side. The hole is used for the terminals of the inner conductors. The laminations are forced in place by a third rail which is also curved and made of alumina ceramic. At each end the lamination are clamped together with two end plates.

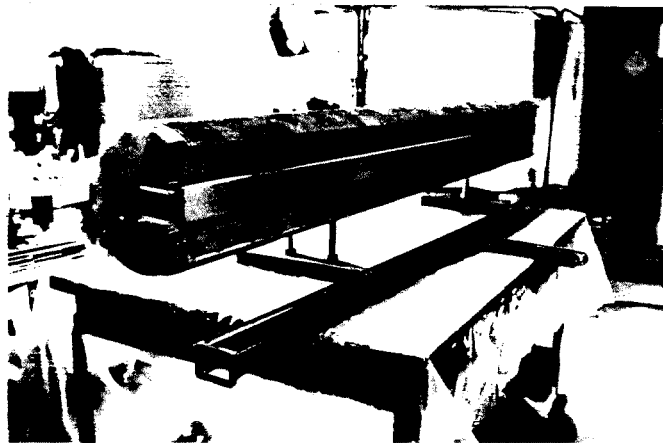


FIG. 4 Magnet assembly before the shield plate and the end vacuum caps are welded in place. A spare coil is on the side.

The coil assembly is put in place through the opening of the septum. The inner insulated conductors are pushed to the rear of the lamination gap and held in place with stainless steel spring clips. The stainless steel support plate is welded to the curved lamination stack. Two 0.13 mm thick Kapton sheets are placed between the stainless steel and the shield plates. The shield plate after welding to the pipe completes the vacuum closure. At each end, vacuum caps are welded with bellows connections to the beam tube.

Septum Magnet Parameters

| | |
|-------------------------------|------------|
| Maximum Field | 6 KG |
| Magnet Length | 2 m |
| Bending radius | 50 m |
| Aperture Width | 5.3 cm |
| Aperture Height | 3.9 cm |
| Septum Thickness | |
| copper | .32 cm |
| stainless steel backing | .47 cm |
| Kapton insulation | .03 cm |
| magnetic shield/vacuum shield | .48 cm |
| | Total |
| Pulsed Current | 1.3 cm |
| Current Drive Frequency | 20,000 AMP |
| Duty Cycle | 1200 Hertz |
| Force on Conductor | .02% |
| Magnet Weight | 296,472 Pa |
| | 550 Kg |

III. Magnetic Measurements

The septum magnet is driven by a 20,000 Amp current pulse delivered by a capacitor discharge. The pulse length is 400 microseconds. We have measured the magnetic field variation across the aperture at the peak of the current pulse. Two probes of length 2.4 m and width 2.5 mm were constructed for measuring the magnet. The probes supported a single turn of wire and were balanced to 2%. A single probe was used to measure the integrated field in the magnet as a function of the discharge capacitor voltage by sending the output into an integrator and displaying the integrator signal on a digital storage scope. The nominal operating point was then selected and the two coils were bucked to produce a difference signal into the integrator. By keeping the position of one coil fixed and moving the other it was possible to measure field variations across the aperture with a resolution of 2×10^{-4} .

Figure 5 shows the measured field variation across the aperture for the first magnet built. All other magnets look essentially the same. The field is extremely uniform from the inner edge of the copper conductor out to 2.5 cm and is within 2×10^{-3} over 3.7 cm. The central field value for this measurement is about 6.0 KGauss. We have also used a single probe to measure the field on the field free side of the septum. The field here is measured to be 1.4 Gauss.

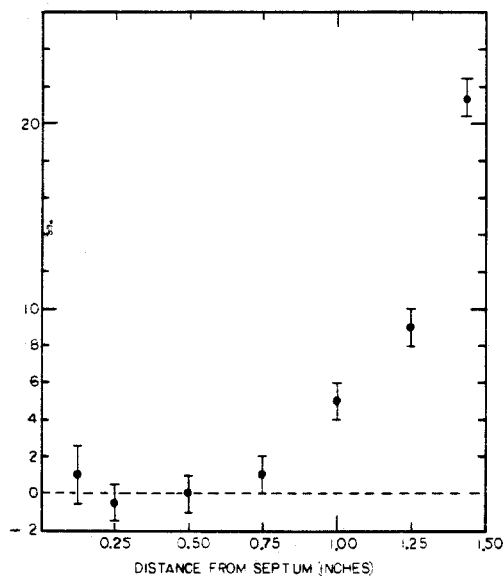


FIG. 5 Magnetic Field Variation Across the Aperture

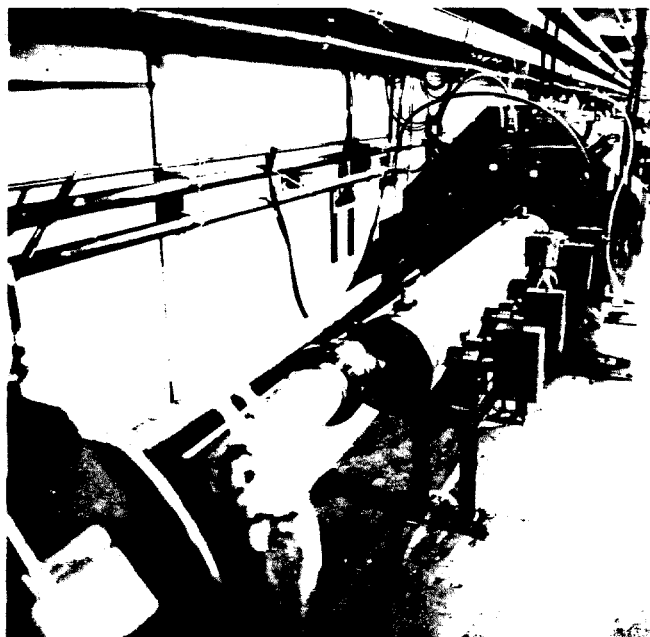


FIG. 6 Septum Magnet at the Debuncher Extraction

IV. Summary

The Debuncher injection septum has been used since early April for injecting 8 GeV protons into the Debuncher. To date it has been pulsed over 90,000 times and is functioning in the intended manner. Three more magnets are being installed for use in commissioning the complete antiproton source complex during May.

Acknowledgements

G. Michelassi and D. Lewis engineered and designed the magnet stands.

We wish to thank A. Bart for drawing the detail design and R. Lebeau for the careful assembly of the septum magnet components.

Reference

1. L.W. Oleksiuk, "Design Study of the Tev I Pulsed Septum Magnet" Fermilab TM-1241-8020.000, Feb. 1, 1984